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CONCERNING THE AUTOMATION OF PROCESSING OF EXPERIMENTAL DATA IN INVESTIGATING THE IRREGULAR IONOSPHERE

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CONCERNING THE AUTOMATION OF PROCESSING OF EXPERIMENTAL DATA IN INVESTIGATING THE IRREGULAR IONOSPHERE

/Following is the translation of an article by V.D. Gusev and T.A. Gaylit entitled "Ob Avtomatizatsii Obrabotki Eksperimental'nykh Dannykh pri Issledovanii Neregulyarnoy Ionosferi" (English version above) in Vestnik Moskovskogo Universiteta, Seriya III, Fiz. Astron. (Herald of the Moscow University, 3rd Series, Phys. Astron.), Moscow, 1960, No. 1, pages 39-49./

The article discusses the circuitry of an electronic correlograph for the calculation of the structure function of a random process having a spectrum of 0-4 cps without previous recording on a photographic film or magnetic tape. The accuracy of calculation is 3%.

The proposed layout can be used for the examination of the dynamics of the fine structure of the ionosphere, and for investigation of any random process with a low-frequency spectrum.

INTRODUCTION

Problems of investigation of the fine structure of the ionosphere are most fully solved at the present time by means of correlation analysis. The calculation of such characteristics of the fine structure as the dimensions of nonuniformities, their anisotropy, the rate of their chaotic variations, direction and velocity of drift, involves analysis of correlation functions of the reflected radio signal amplitudes as observed at three spatially separated points /1/.

Inasmuch as regular observation of the state and particularly the changes of the nonuniform structure of the ionosphere is of interest, it is necessary to automate the processing of the data at least partially; the correlation function in particular should be obtained automatically, because the calculation and manual construction of these functions is quite time consuming.

In the correlators described in the special literature (see, for example, /2/), the process being investigated is recorded on a photographic film or magnetic tape and then processed n times through the correlator (n is the number of points of the function to be calculated).

For solution of the special problem arising in ionospheric measurements, a simpler device can be con-

structed which determines simultaneously n points of the function being calculated without a previous recording of the process.

Considerable simplification of the circuits can be achieved by using discrete selection.

In processing, the continuous process is replaced by discretely selected values spaced at a time interval t_0. The integration of the correlation function

$$R(\tau) = \frac{1}{T} \int_0^T x(t)\, x(t+\tau)\, dt$$

is replaced by the summation

$$R(\tau) = \frac{1}{N} \sum_{K=0}^{N-1} x(t+Kt_0)\, x(t+Kt_0+\tau).$$

A time interval t_0 for which two successively selected quantities $x(t)$ and $x(t+t_0)$ do not correlate mutually is the most rational /4,5/. Let us note that the use of discrete periodic selection is possible for random processes only. For periodic processes, such selection will, in general, give incorrect results.

Section 1.

The peculiarities which arise in connection with

construction of a correlation device for study of the fine structure of the ionosphere are:

1. The part of the frequency spectrum of the random process to be investigated is 0-3 cps. The radii of correlation vary from one to several seconds. Thus the range from 0.1 to several seconds is a satisfactory retardation time.

2. The problem of the averaging time of the process has not been fully resolved. An increase in the averaging interval reduces the statistical error of the function determination, but the presence of large nonuniformities in the ionosphere leads to instability of the process, and plays an important role in the case when the time of integration is of the same order as the period of a large nonuniformity. The optimum integration time is three minutes. Here, the integration interval contains 60-100 correlation radii of the process, the statistical error in determining the correlation function is 10-15% /3/, and the averaging time is a fraction of the period of the large nonuniformities (15-20 minutes).

3. Since the statistical errors in determination of the function may be relatively large (10-15%), the precision of the apparatus need not be too high.

Section 2.

Any function simply connected to the correlation function may be taken as the function to be calculated. Such a function, for example, is the structure function.

$$f_{xx}(\tau) = \overline{(x - x_\tau)^2} = 2\sigma^2 (1 - R_{xx}(\tau)).$$

Here $x = x(t)$,

$$x_\tau = x(t + \tau),$$

$$\sigma^2 = \overline{x^2} - \overline{x}^2,$$

$$R_{xx}(\tau) = \frac{\overline{xx_\tau} - \overline{x}^2}{\overline{x^2} - \overline{x}^2}.$$

In a similar manner, it is possible to set up the structure function reciprocally:

$$f_{xy}(\tau) = \overline{(x - y_\tau)^2},$$

$$\text{if } \overline{x} = \overline{y},\ \sigma_x^2 = \sigma_y^2 = \sigma^2,\ f_{xy}(\tau) = 2\sigma^2 [1 - R_{xy}(\tau)].$$

If x and y are amplitudes of a reflected signal observed at two separate points in space, the assumption of equality of the averages and dispersions of these quantities corresponds to the assumption of a steady and uniform statistical ensemble of measured amplitudes. For this condition, which is usually assumed to hold, the norms of the structure functions of the amplitudes are equal when they are observed at points separated in space. Therefore, if three receiving channels with equal amplification at the operat-

ing frequency are used, there is no need for normalization of the structure functions for calculating all average parameters of the motion and the geometry of the diffraction pattern, except for the correlation radius. If necessary, the function may be normalized with the aid of the correlator to be described (see Section 5).

The structure function is better suited for automatic computation than the correlation function for the following reasons:

1. Fewer and simpler operations are required for calculation of the structure function.

2. The calculation of the correlation functions requires very high accuracy in some operations. Indeed, the difference $\overline{xy_\tau} - \bar{x}\bar{y}$ for a random process is considerably smaller than each of the above terms $\overline{xy_\tau}$ and $\bar{x}\bar{y}$. The storage, multiplication, integration, and subtraction errors apply precisely to the quantities $\overline{xy_\tau}$ and $\bar{x}\bar{y}$. The relative error of the difference may be several times greater than the errors of the subtrahend and minuend. In calculating the structure function, only storage and subtraction errors can give this effect, and higher requirements are set up for the precision of these operations.

We can also use a simpler function — the average modulus of the difference $\overline{|x - x_\tau|}$. The advantages of this

function are obvious. A disadvantage, however, is that this function is in known relationship to the correlation function only for the normal and Rayleigh distributions.

Below, a device for setting up the structure function of a random process is discussed, but its principles are also applicable to computation of the correlation function.

Section 3.

The process of computing a structure function may be divided into the following steps: time delay of the process, subtraction, squaring, integration and display.

Figure 1 shows the block diagram of the equipment, and Fig. 2 shows the shape of the voltages at different points of the circuit.

A capacitor is used as a storage device. Switching of the capacitor and all other commutations are effected using a type ShI-26 stepping switch. The capacitor, which is connected to the moving contact of this selector, is charged through the first stationary contact to the voltage $x(t)$ being examined at the start of the cycle. Then the capacitor is connected in series with the input of the subtracting unit at the moments of time $t+\tau_1$, $t+\tau_2$, etc., thereby supplying constant-amplitude pulses till the be-

ginning of the next cycle. In the next cycle, the constant value to be stored is approximately equal to the voltage being studied at the moment of time $t+t_0$, etc.

The time-variable voltage being studied is applied to the second input of the subtracting unit, again by means of the stepping switch.

Thus, the input of the subtracting device receives two voltages with different time shifts. Therefore, n points of the correlation function can be found by one subtracting and squaring unit.

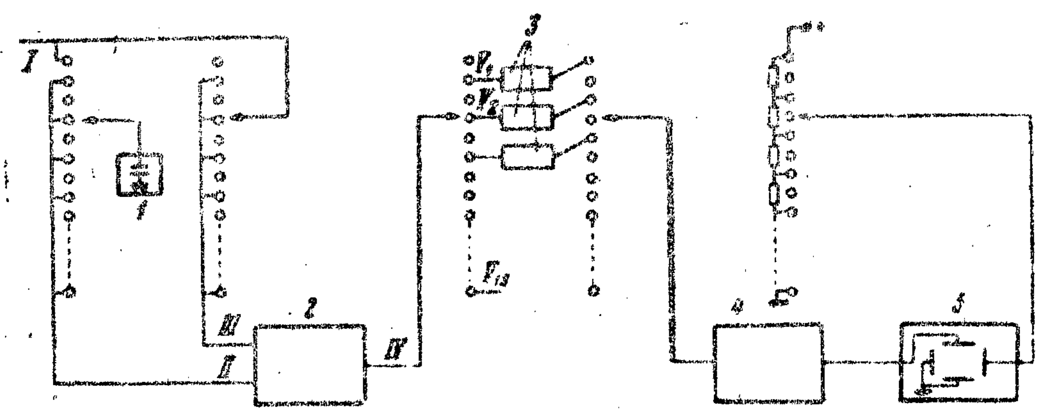

Fig. 1. Block diagram of an automatic structure-function computer: 1) storage element; 2) subtracting and squaring unit; 3) integrators; 4) direct-current amplifier; 5) indicator tube with photo attachment.

The square of the unknown voltage is supplied to the integrators through another bank of the stepping switch

in such a manner that the results of subtraction and squaring which belong to one value of the time shift are added in each integration. After completing the integration, the voltage is taken from the integrators by the stepping switch and supplied via the direct-current amplifier to the vertical deflecting plates of the indicating oscilloscope. Here, a discrete sweep is supplied to the horizontal deflection plate. Thus the structure function is displayed on the tube screen, and can be observed visually or photographed.

Let us now consider the details of the separate blocks:

1. The storage errors result from incomplete charging of the capacitor and partial discharge on connection to the subtracting unit.

The conditions for the minimum storage errors are:

$$\Delta t \gg R_{зар} C,$$

$$n\Delta t \ll R_{разр} C,$$

1) charging; 2) discharging.

where Δt is the duration of the stepping-switch's contact time and depends on the velocity of its motion; n is the number of points of the function to be calculated.

The maximum frequency of the process which is not distorted by the selector and the duration of the delays which can be achieved with the apparatus are dependent upon

the velocity of movement.

In our case, $C_{stor} = 25\mu F$, $R_{dis} = 9.5$ megohms, and $R_{ch} = 500$ ohms. These parameters ensure an accuracy of 0.5% for a stepping-switch rate of 10-20 steps per second. The upper passed frequency is 2-3 cps, the minimum delay is 0.05 seconds, and the maximum is 3 seconds.

2. We obtain the absolute value of the difference at the output of the subtractor, because the dynamic range doubles when the modulus is fed to the input of the square-law generator. The error of the subtractor, referred to the maximum value of the difference, is 0.5%.

3. Squaring is carried out on alternating current. Triangular pulses with period and amplitude proportional to the input voltage are shaped in the square-law generator. The error of this generator, referred to the whole range of its operation, is 1%.

The circuits of the subtracting and squaring devices are shown in Fig. 3.

4. Rather large RC networks (RC = 104 sec) are used as integrators in the circuit. The use of such simple integrators is possible because due to the switching of the selector switch, the integration time is a fraction of the time during which the process is being examined.

If the process-examination time is 2-3 minutes,

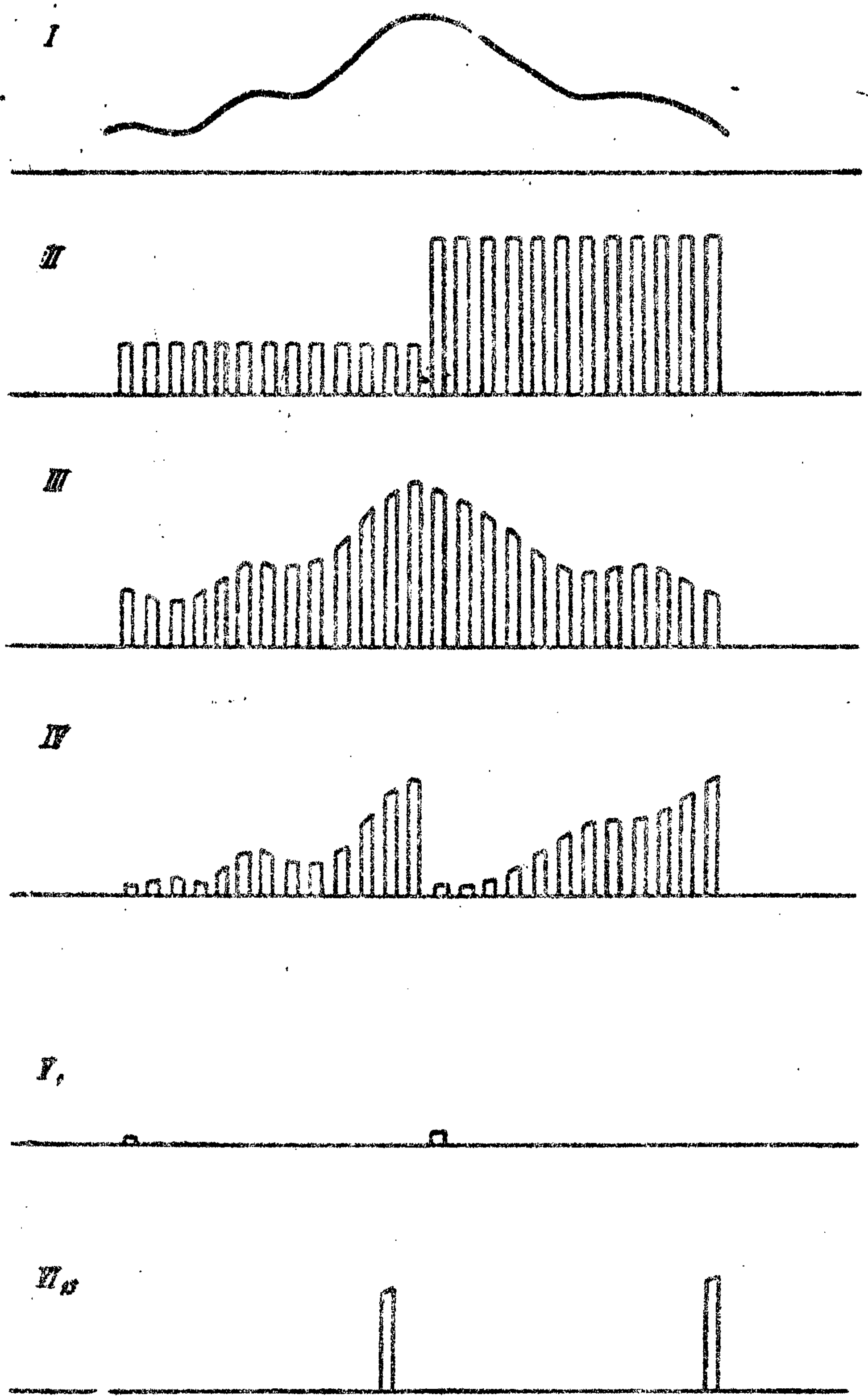

Fig. 2. Shape of voltages at different points of the block diagram in Fig. 1.

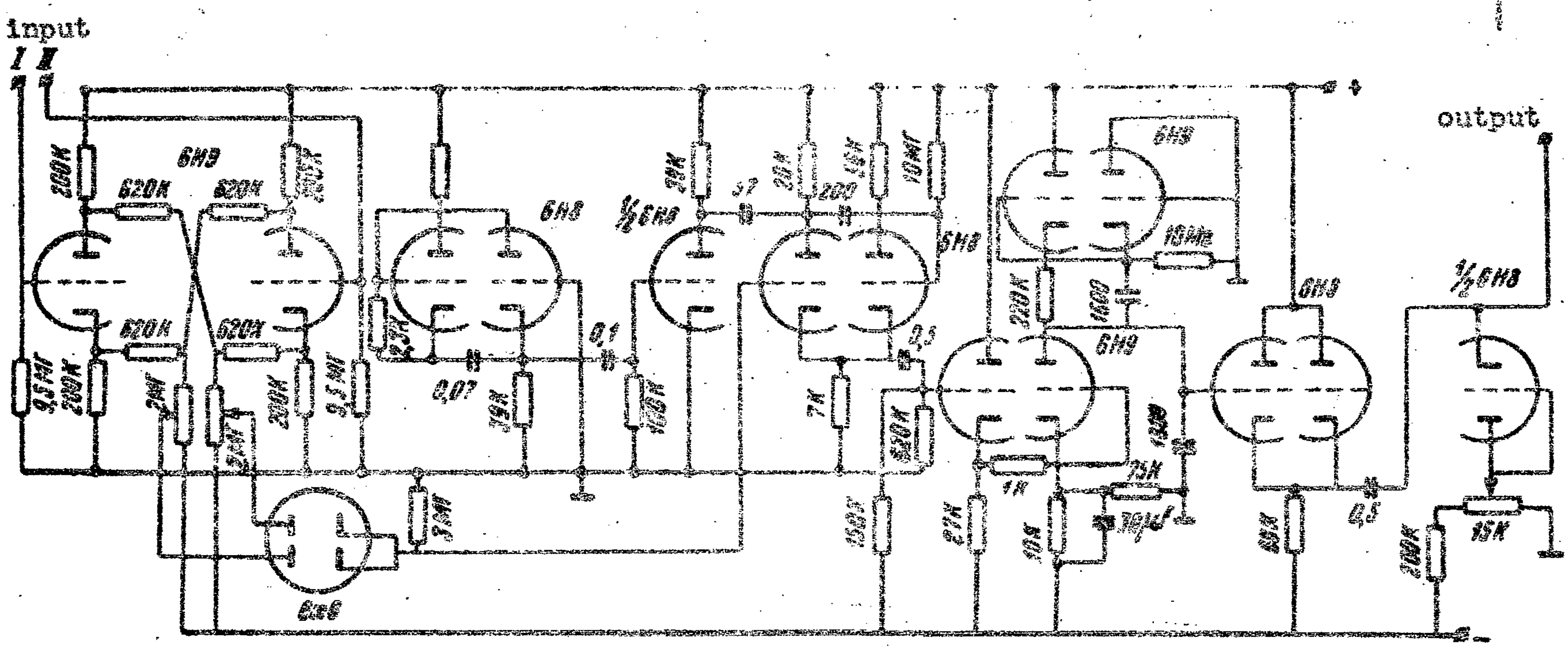

Fig. 3. Schematic diagram of subtracting and squaring unit.

6x6 = 6Kh6
Н = N
МГ, Мг = megohms
К = kilohms

the operation time of the integrator is only about 5-7 seconds. For RC ≈ 104 sec, the error of integration is 2.5-3%.

Tube circuits should be used to obtain high precision.

5. As noted above, the indicator is an oscilloscope, and the calculated function is displayed as a series of discrete points on its screen.

6. The possibility of error due to incorrect transmission of the voltages by the stepping switch, especially for values $\ll 1$ v, should be noted. In order to eliminate errors of this kind, the condition of the selector contacts must be checked.

Section 4.

A noise generator was used for a final check of the operation of the apparatus; this generated noise with a known correlation function which, in its spectral composition and distribution, approximated the random variation of the amplitude of a signal reflected by the ionosphere. The apparatus was used for computing the structural function and the average difference modulus of the random process. The noise amplitude was simultaneously recorded on photographic film and tabulated, and the same function computed on a type SASL computer.

In order to separate the instrumental error from

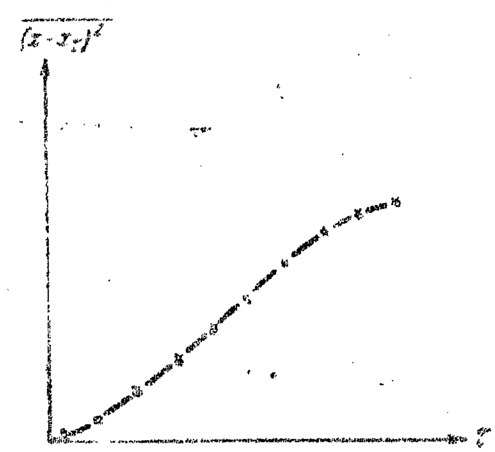

Fig. 4. Structure function of a random process: O — points obtained with the correlator; + — calculated points.

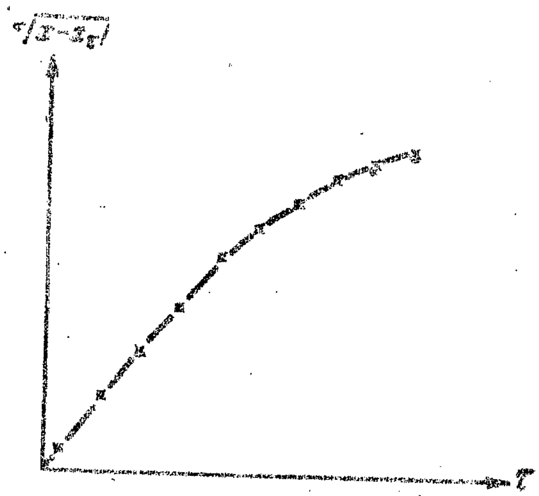

Fig. 5. Mean modulus of difference of a random process: O — points obtained with the correlator; + — calculated points

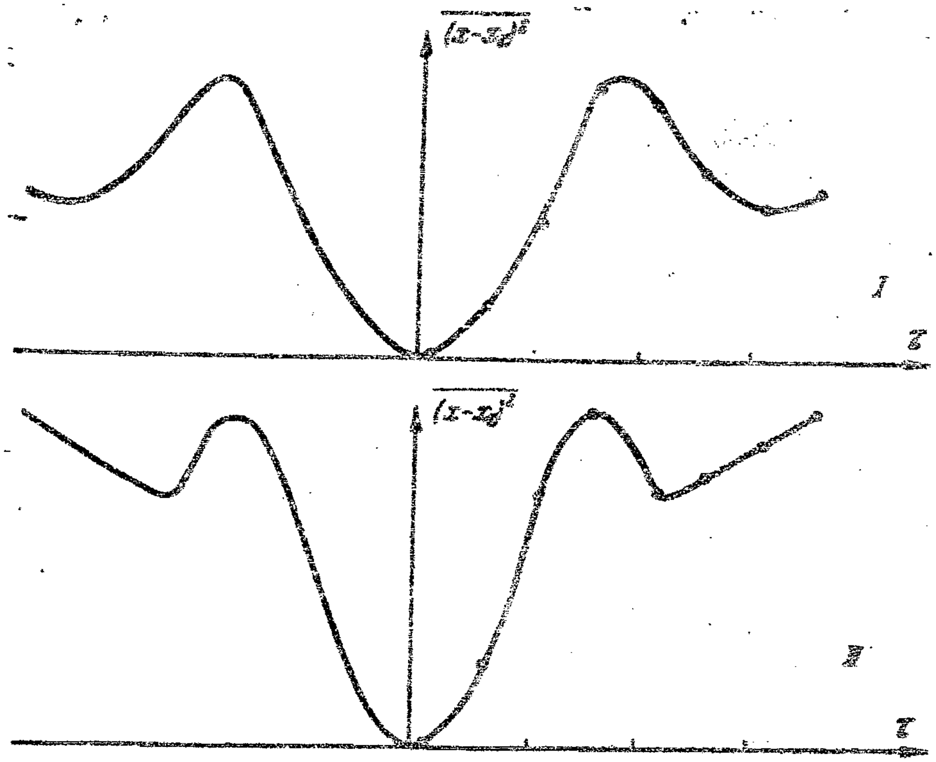

Fig. 6 [Continued on following page.]

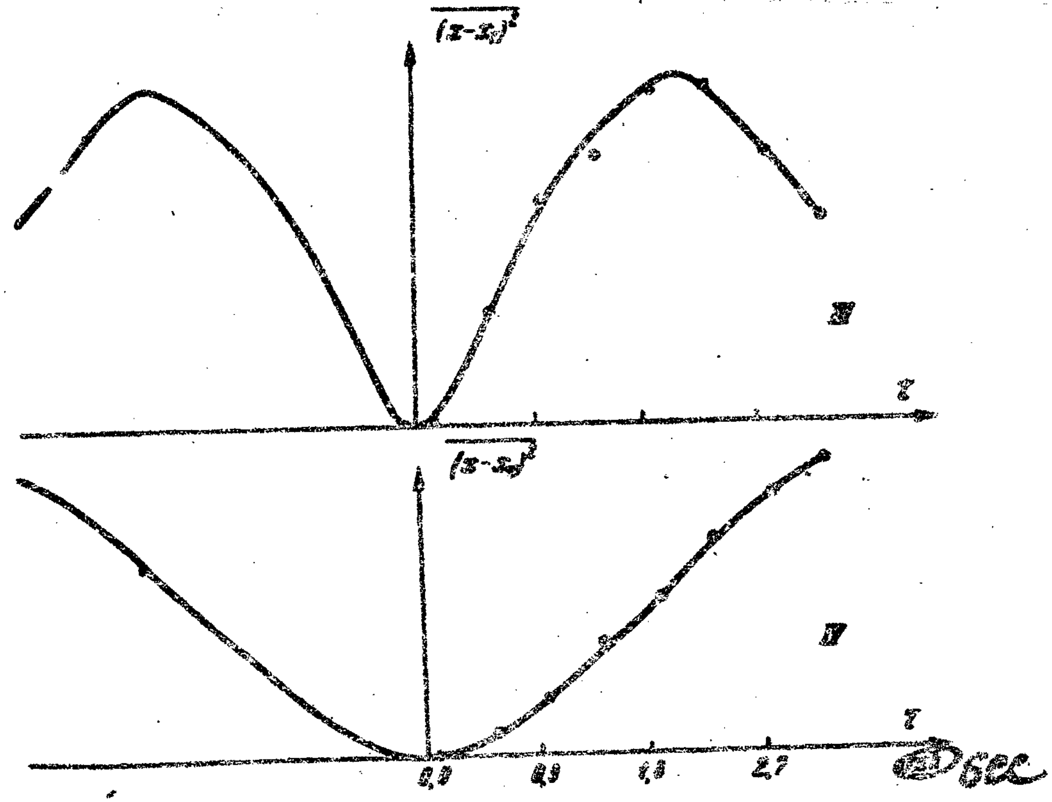

Fig. 6. Time variation of structure function of the amplitude of a signal reflected from the ionosphere: I — 14.24-14.27; II — 14.36-14.39; III — 14.48-14.51; IV — 15.00-15.03 (Moscow decree time).

the statistical error due to the finite discrete selection, discrete values of the amplitude selected by the apparatus were brightend for photography of the noise; then discrete amplitude values selected by the instrument were read.

Figure 4 shows structure functions of a random process obtained with the apparatus and computed with an SASL. Figure 5 shows the corresponding mean moduli of the difference. Such a comparison was repeated several times. The instrumental error amounts to approximately 2% for the mean modulus, and 3-4% for the structure function, when it is referred to the maximum calculated value. It should be noted that the tabulation error is included in this error.

Figure 6 shows several structure functions of the amplitude of a signal reflected from the ionosphere as obtained with the correlator.

Section 5.

Owing to the application of discrete selection, it is possible to obtain within the same time interval four structural functions for three signals with one function generator. This is necessary in investigations of the ionosphere.

This is achieved by alternately feeding signal

amplitudes from all three observation points to the input of block 2 (Fig. 1) with the aid of the selector switch in such a manner that three amplitudes with all time shifts are on the same time axis. The separation of these values for the respective integrators is accomplished by the stepping switch.

The norm of the structure function $2\sigma^2$ is equal to $\overline{(x - x_\tau)^2}$ for τ for which $R(\tau) = 0$. The delay of the process by a time τ 4-5 times greater than the radius of correlation is achieved by an additional element consisting of storage capacitors and a stepping switch which has a rate 1/4 to 1/5 that of the other selectors. Subtraction and squaring of this term is obtained by using the blocks described above.

In this manner, one of the points on the indicator (for example, the last one) will correspond to $2\sigma^2$ or the unit level of the function being computed.

CONCLUSIONS

The operating principle of the automatic equipment discussed above is applicable to the processing of random process data with a frequency spectrum of 0-3 cps. The spectrum can be broadened by increasing the speed of the stepping switch and by appropriate variation of the

equipment parameters. The error of the equipment is 2-4%.

The electrical circuitry of the system is simple; it contains eleven electron tubes, not counting the indicator tube and the power supply.

There are no special mechanical devices requiring precision fabrication, such as tape transports.

The computing time of the function coincides with the time of observation of the process; there is no time loss for preliminary fixation; therfore the variations of the correlation characteristics of the reflected field can be examined.

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